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ORIGINAL ARTICLE

Different displacement of bioimpedance vector due to Ag/AgCl electrode effect

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BACKGROUND/OBJECTIVES: Bioelectrical impedance vector analysis (BIVA) is increasingly used in clinical research to assess soft tissue hydration. It is known that physical characteristics of electrodes, such as low intrinsic impedance, low electrode/skin contact impedance and type of gel, affect the reliability of noninvasive bioimpedance assessments. The aim of this study was to determine the effect of intrinsic impedance of electrode on the bioimpedance vector displacement in RXc graph.

SUBJECTS/METHODS: The intrinsic impedance is measured in nine pregelled disposable Ag/AgCl electrodes usually used for bioimpedance measures. The BIVA method is performed on 35 healthy volunteers using a 50 kHz phase-sensitive bioimpedance analyzer (BIA 101 Anniversary) with the lowest intrinsic impedance electrode and highest. The individual bioimpedance vector is plotted on the bivariate normal interval of reference population. The differences in the mean bioimpedance vectors obtained with each electrode are plotted, with their 95% confidence ellipses, on the dRXc graph. The paired one-sample Hotelling's T^2-test is used to compare the differences of the mean bioimpedance vectors.

RESULTS: We found large variability in intrinsic resistance (11–665 Ω) and reactance (0.25–2.5 Ω) values of the electrodes analyzed and significant displacement ($P < 0.05$) of bioimpedance vector positions in healthy adults according to the paired one-sample Hotelling's T^2-test.

CONCLUSIONS: A robust study of all physical characteristics of commercial Ag/AgCl electrodes is necessary to reach consensus on pregelled Ag/AgCl electrodes valid for bioimpedance measurement. This information will enable BIVA users to avoid systemic errors when performing BIVA assessments, specifically when these measurements are used for clinical interpretations.

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INTRODUCTION

The use of bioelectrical impedance methods to assess the structure and function of biological entities continues to increase at a rapid pace.[1] These noninvasive methods use modern electronic devices to introduce a safe alternating current into the body at single or multiple frequencies and to measure passive bioelectrical properties that are related to physiological parameters or body composition. A key component of bioimpedance methods is the use of contact surface electrodes, although its use is not universal. Indeed, the use of steel contact electrodes as used in stand-on-type devices is increasing.

Despite the plethora of research published using these methods, a conspicuous gap exists in standardization of the electrodes required to measure bioelectrical variables *in vivo*. Guidelines from the NIH Technology Assessment Conference on Bioelectrical Impedance Analysis,[2] a subsequent follow-up review,[3] and the European Society for Parenteral and Enteral Nutrition[4] only address the size of the electrodes and separation between source and detector electrodes for tetrapolar measurements. The topic of characteristics of the contact electrodes is not fully addressed.

Surface electrodes composed of silver-silver chloride (Ag/AgCl) are a common component of bioimpedance systems that are routinely used in a wide range of biomedical applications. The scientific basis for the use of Ag/AgCl surface electrodes is well established for noninvasive assessment of bioelectrical signals.[5–10] Webster[11] emphasized that theoretically every Ag/AgCl electrode should have the same intrinsic impedance half-cell potential, but he also anticipated that differences probably exist among Ag/AgCl electrodes and it can introduce errors into bioelectrical measurements.

Concern about variability of intrinsic *Z* among commercial Ag/AgCl electrodes persists. Shiwei *et al.*[12] found disparity in the measured impedance values among the same volunteers with different pregelled Ag/AgCl commercial electrodes. Emerging evidence indicates the need to evaluate commercial Ag/AgCl electrodes for bioimpedance applications.

Some researchers recommend the use of contact Ag/AgCl electrodes with appropriate characteristics (example, low intrinsic *Z* and low electrode/skin contact impedance, type of gel), careful placement of the electrodes and avoidance of expired electrodes to minimize measurement errors.[8–10,13,14] The electrode/skin contact impedance depends on the type and preparation of the skin and the time the electrode has been placed. Usually, it is a measure using the three-electrode configuration.[10]

There are different methods for assessment of body composition by noninvasive measures of bioelectrical impedance. An alternative impedance approach is the utilization of the spatial relationships between resistance (*R*) and reactance (Xc) to assess soft tissue hydration by RXc graph, called the bioelectrical

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impedance vector analysis (BIVA) method,[15] which has become one of the most used in clinical applications in the last 20 years.

The BIVA method has been validated in numerous clinical research such as hemodialysis,[16–18] peritoneal dialysis,[19,20] obesity,[21] heart failure,[22] anorexia nervosa,[23] pediatrics,[24–28] healthy adults,[28–31] geriatrics[32–34] or lung cancer.[35] The main advantage of this method is the lack of reliance on any assumption about constant soft tissue hydration and chemical composition of the fat-free body, and its independence from the use of body weight for any assessment. Thus, BIVA only depends on the reproducibility and accuracy of bioimpedance measurements and intraindividual variability in body composition. Other advantages of the method are its simplicity and objectivity.[36]

The objective of this research was to determine the effect of intrinsic impedance of pregelled Ag/AgCl electrodes on displacement of impedance vectors using the BIVA method on healthy human volunteers. We tested the hypothesis that differences in intrinsic electrode impedance affect the displacement of impedance vectors, determined by the BIVA method, used in clinical assessments.

MATERIALS AND METHODS

Measurement protocol in volunteers

This was a cross-sectional study performed on a convenience sample of 35 Italian healthy volunteers aged 30–50 years. Potential volunteers were excluded if they had any underlying medical conditions or current infections, if they were taking any drugs that could influence bioimpedance measurements and if they had physical abnormalities (amputations and so on). All measurements were performed on a single day by trained staff according to standardized protocols. Informed consent was obtained from all subjects, and the Ethics Committee 'Comitato Etico Indipendente c/o Fondazione PTV Policlinico Tor Vergata' approved the study.

BIVA of tetrapolar whole-body measure was performed on 35 healthy volunteers: 15 males (age: 30–50 years; height: 1.77 (0.05) m; weight: 76.6 (13.8) kg; body mass index (BMI) 24.7 (3.9) kg/m^2) and 20 females (age: 30–50 years; height: 1.65 (0.03) m; weight: 57.3 (4.0) kg; BMI 21.0 (1.9) kg/m^2) who underwent standard whole-body tetrapolar bioimpedance measurements. The volunteers were measured in a supine decubitus position on a non-conductive litter in the biomedical laboratory (22–24 °C). Two electrodes injecting the current (*I*) and two electrodes detecting voltage (*V*) and phase were dorsally placed on the right hand in the third metacarpus-phalangeal articulation and in the carpus, respectively. The pair on the foot was located in the third metatarsus-phalangeal and in the articulation.[37]

The bioimpedance measurements were measured using two commercial Ag/AgCl electrodes with different intrinsic impedance. The order of electrode use was randomized for each volunteer. Technical staff used cotton swabs soaked with alcohol to cleanse the skin before each electrode application. Measurements were performed 10 min after electrode placement, which is grounded on the recommendation of Bolton *et al*.[13]

A calibrated scale (SECA 700 Mechanical Scale; Seca Corp., Hamburg, Germany) and wall-mounted stature meter (SECA 240; Seca Corp.) were used to measure body weight and standing height, respectively.

The measurements were performed with a bioimpedance analyzer (BIA 101 Anniversary; AKERN-Srl, Florence, Italy) that applied a constant current of 240 μA_{RMS} at 50 kHz, sine, phase-sensitive impedance instrument with a range of measure for $R = 0–1500\ \Omega$ and Xc 0–500 Ω. Tolerance was 2% max.

Intrinsic impedance measure of commercial Ag/AgCl electrodes

The intrinsic impedance variables (*R*, Xc and *Z*) were measured using commercial Ag/AgCl electrodes from six different manufacturers. Characteristics of the electrodes (contact surface area, shape, snap or tap electrode) are shown in Table 1. All electrodes were used within 1 year before the expiration date.

Figure 1 shows the arrangement of electrodes and the dual layer of matched electrodes to determine the intrinsic impedance for each pair of the nine Ag/AgCl electrodes analyzed.

A 50 kHz, phase-sensitive device (BIA 101 Anniversary) with a tetrapolar electrode method introduced a sinusoidal AC of 240 μARMS and measured *R*, Xc and phase angle (PhA). Calibration of the system was confirmed with

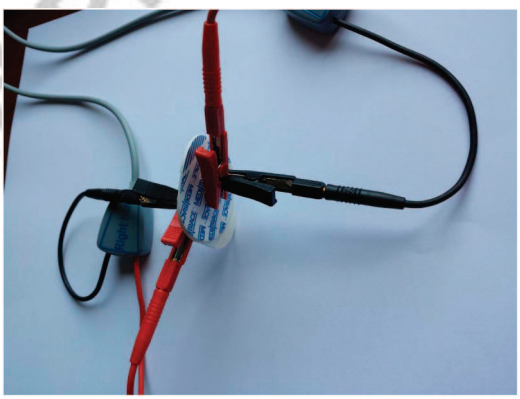

Figure 1. Electrode wafer to measure intrinsic impedance with a phase-sensitive 50 kHz bioimpedance device. Red clips inject current and black clips sense voltage.

Table 1. Characteristics of the nine commercial electrodes used in bioimpedance measurements

Manufacturer	*Reference of electrode*	*Conductive surface area (cm^2)*	*Snap or tab electrode*	*Shape*
COVIDIEN-Kendall	5500 Diagnostic tab electrodes/30807732	5.75 cm^2 (2.3 × 2.5 cm^2)	Tab	Rectangular
	200 Foam electrodes/31050522	4.40 cm^2	Snap	Circular
AKERN-Srl	BIATRODES/0ELB	7.83 cm^2 (2.7 × 2.9 cm^2)	Tab	Rectangular
ImpediMed	IU0GELTD	5.75 cm^2 (2.3 × 2.5 cm^2)	Tab	Rectangular
3M	Red Dot/2239	2.45 cm^2	Snap	Circular
	Red Dot/2228	13.2 cm^2 (4.0 × 3.3 cm^2)	Snap	Rectangular
Ambu	WS-00-S	8.57 cm^2	Snap	Circular
	SU-00-C	7.72 cm^2	Snap	Circular
ConMed	Softrace Large/2350	5.75 cm^2 (3.2 × 3.2 cm^2)	Snap	Square

a precision parallel circuit formed by a 384 Ω (±1%) resistor parallel with 780 pF (±2%) capacitor.

Measurements of the intrinsic impedance of the electrodes (that is, *R*, Xc and *Z*) were performed on five pairs of each type of commercial electrodes of the same batch to check the intraelectrode variability of the intrinsic impedance values for each type of the commercial electrodes used.

BIVA method

The BIVA method is based on the measurement of the complex electrical impedance in whole-body (right-side) configuration. The components of the impedance vector, *R* and Xc, are normalized by the height of the subjects (*R*/*H* and Xc/*H*) and represented in the RXc graph (abscissa *R*/*H*, ordinate Xc/*H*). The vector measured in an individual is compared against the normal interval of the reference population, as expressed in percentiles of 50, 75 and 95% of the normal distribution (Gaussian) bivariate, the probabilistic graph. The correlation between *R* and Xc determines the ellipsoidal form of the bivariate probability distributions. Variations in the structure of soft tissue are associated with a migration of the vector in the smaller axis (Xc/*H*) direction of the ellipses, with either an increase or a decrease in the PhA, whereas combined variations of hydration and nutrition are associated with migration of the vector in the direction of the combination of the two principal directions.[15]

In this study, the individual bioimpedance vectors obtained with each electrode were plotted on the tolerance ellipses (RXc graph) of the Caucasian ethnicity adult population[32] by using the BIVA software.[38] The 95% confidence ellipses for mean vectors of the measurements performed with each electrode were drawn to assess the effect of the intrinsic impedance of the electrodes on bioimpedance measurements.

Statistical analysis

The differences in the mean bioimpedance vectors obtained with each electrode were plotted, with their 95% confidence ellipses, on the dRXc graph. The paired one-sample Hotelling's T^2-test,[39] a multivariate extension of the Student's *t*-test for paired data, was used to compare the differences of the mean bioimpedance vectors. If a 95% confidence ellipse of a vector displacement covers the null vector (that is, abscissa 0, ordinate 0), the vector displacement is not statistically significant ($P < 0.05$) at a paired one-sample Hotelling's T^2-test.[38]

Student's *t*-test for paired data was used to compare the bioelectrical parameters (that is, *R*, Xc, *R*/*H*, Xc/*H* and PhA) measured with the electrodes of different intrinsic *R* and Xc for each subject, and repeated-measures analysis of variance was applied to assess differences in the five measurements of the intrinsic *R*, Rc and impedance values performed for each type of electrodes. Finally, statistical analysis of the interelectrode comparisons was performed using one-way analysis of variance. Statistical analysis was carried out using the SPSS version 19.0 (SPSS, Chicago, IL, USA). It was performed by an independent statistician, blinded for the reference numbers of the electrodes. All data are presented as mean (s.d.). The normality of the distribution of the variables was checked by the Shapiro–Wilk test and the homogeneity of variances by Levene's test.

RESULTS

Table 2 shows the measurements of the intrinsic *R*, Xc and *Z* values described as mean (s.d.), measured at 50 kHz, for each pair of the nine electrodes analyzed with the dual-layer wafer method. No significant differences were observed in the repeated measurements of the intrinsic *R*, Xc and *Z* values for each pair of the electrodes of the same type. However, the variability of the intrinsic *R* and Xc between the different types of electrodes was ~11–665 and 0.25–2.5 Ω, respectively. The intrinsic *R*, Xc and *Z* values were statistically different between all the electrodes analyzed, except (1) *R* and *Z* values for Ambu/WS-00-S and ImpediMed-IU0GELTD electrodes and (2) Xc values for Ambu/SU-00-C and COVIDIEN-Kendall/30807732 electrodes, and Xc values for ImpediMed-IU0GELTD and 3M Red Dot/2239 electrodes.

Table 3 shows *R* and Xc values obtained on whole-body configuration, with electrode COVIDIEN-Kendall/31050522 and with electrode Ambu/SU-00-C in 35 healthy volunteers. *R*/*H* and Xc/*H*, PhA and linear coefficient correlation *r* (*R*, Xc) are also shown in Table 3. The mean values of the bioelectrical parameters of the volunteers measured with the electrodes that showed the highest intrinsic impedance (Ambu/SU-00-C) were significantly higher compared with those obtained with the electrodes that showed the lowest intrinsic impedance (COVIDIEN-Kendall/31050522). Specifically, the PhA values obtained with the electrode COVIDIEN-Kendall/31050522 were ~1° lower compared with those obtained with the electrode Ambu/SU-00-C.

Figure 2 shows the individual bioimpedance vectors for 15 male and 20 female healthy volunteers, obtained with the BIVA software,[38] on the bivariate normal interval of reference population[35] separated by gender and determined with the electrodes, which had the lowest and the highest intrinsec impedance (COVIDIEN-Kendall/31050522 and Ambu/SU-00-C, respectively).

Figure 3 shows the 95% confidence ellipses corresponding to COVIDIEN-Kendall/31050522 and Ambu/SU-00-C plotted on the bivariate normal interval of reference population.[35] The paired graph shows the 95% confidence ellipse corresponding to the difference in the mean bioimpedance vector obtained with the electrodes COVIDIEN-Kendall/31050522 and Ambu/SU-00-C (Figure 4) for males (blue line) and females (red line). The 95% confidence ellipse of the vector displacement does not cover the null vector (that is, d*Z*/*H* = 0.0), indicating a statistically significant vector displacement ($P < 0.05$) at a paired one-sample Hotelling's T^2-test.[38]

Table 2. *R*, Xc and *Z* intrinsic values determined, at 50 kHz, for the nine commercial electrodes used in bioimpedance measurements

Electrode/reference	R *(Ω)*	*Xc (Ω)*	Z *(Ω)*
COVIDIEN-Kendall/30807732	347.19 (0.04)[a,b,c,d,e,f,g,h]	2.50 (0.00)[a,b,c,d,e,f,h]	347.20 (0.04)[a,b,c,d,e,f,g,h]
COVIDIEN-Kendall/31050522	10.89 (0.04)[b,c,d,e,f,g,h]	0.30 (0.00)[b,c,d,e,f,g,h]	10.89 (0.04)[b,c,d,e,f,g,h]
AKERN-BIATRODES/0ELB	25.74 (0.04)[c,d,e,f,g,h]	0.45 (0.00)[c,d,e,f,g,h]	25.74 (0.04)[c,d,e,f,g,h]
ImpediMed-IU0GELTD	27.13 (0.05)[d,e,g,h]	0.90 (0.00)[e,f,g,h]	27.14 (0.05)[d,e,g,h]
3M Red Dot/2239	15.75 (0.04)[e,f,g,h]	0.90 (0.00)[e,f,g,h]	15.77 (0.04)[e,f,g,h]
3M Red Dot/2228	24.75 (0.04)[f,g,h]	0.70 (0.00)[f,g,h]	24.76 (0.04)[f,g,h]
Ambu/WS-00-S	27.24 (0.04)[g,h]	0.25 (0.00)[g]	27.24 (0.05)[g,h]
Ambu/SU-00-C	665.37 (0.04)[h]	2.50 (0.00)[h]	665.37 (0.04)[h]
ConMed/2350	30.23 (0.04)	0.25 (0.00)	30.23 (0.04)

Results are described as mean (s.d.). Abbreviations: R, resistance; Xc, reactance; Z, impedance. [a]Mean values were significantly different from those of the COVIDIEN-Kendall/31050522 ($P < 0.05$). [b]Mean values were significantly different from those of the AKERN-BIATRODES/0ELB ($P < 0.05$). [c]Mean values were significantly different from those of the ImpediMed-IU0GELTD ($P < 0.05$). [d]Mean values were significantly different from those of the 3M Red Dot/2239 ($P < 0.05$). [e]Mean values were significantly different from those of the 3M Red Dot/2228 ($P < 0.05$). [f]Mean values were significantly different from those of the Ambu/WS-00-S ($P < 0.05$). [g]Mean values were significantly different from those of the Ambu/SU-00-C ($P < 0.05$). [h]Mean values were significantly different from those of the ConMed/2350 ($P < 0.05$).

Table 3. Bioelectrical parameters determined, at 50 kHz, for the two commercial electrodes used for bioimpedance measurements in the volunteers

	Males (n = *15*)		*Females* (n = *20*)	
	COVIDIEN-Kendall/31050522	*Ambu/SU-00-C*	*COVIDIEN-Kendall/31050522*	*Ambu/SU-00-C*
R (Ω)	466.2 (89.0)[a]	470.7 (86.6)	572.8 (67.2)	574.7 (69.6)
Xc (Ω)	55.8 (9.6)[a]	64.2 (9.3)	65.6 (9.5)[a]	75.0 (8.7)
Z (Ω)	469.6 (89.1)[a]	475.1 (86.6)	575.9 (67.5)	579.6 (69.8)
R/H (Ω/m)	254.5 (50.7)	266.2 (51.5)	343.3 (36.4)	347.3 (40.6)
Xc/*H* (Ω/m)	31.0 (5.7)[a]	36.3 (5.5)	38.9 (5.1)[a]	45.4 (5.4)
Z/H (Ω/m)	265.6 (52.9)[a]	268.7 (51.5)	348.0 (39.2)	350.3 (40.8)
PhA (deg.)	7.0 (1.1)[a]	7.9 (1.0)	6.5 (0.7)[a]	7.5 (0.7)

Abbreviations: COVIDIEN-Kendall/31050522, electrodes with the lowest intrinsic impedance; Ambu/SU-00-C, electrodes with the highest intrinsic impedance; R/H, resistance normalized by height; Xc/H, reactance normalized by height; Z/H, impedance normalized by height; PhA, phase angle. Results are described as mean (s.d.). [a]Mean values were significantly different from those of the Ambu/SU-00-C ($P < 0.05$).

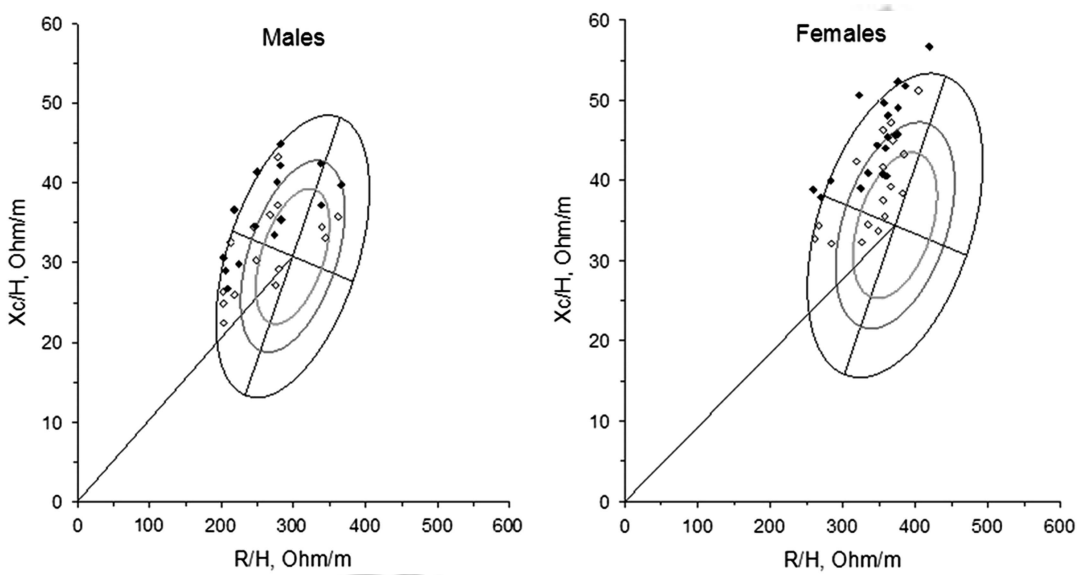

Figure 2. Individual vectors for 35 healthy volunteers (15 males and 20 females) on the tolerance ellipses (50, 75 and 95% percentiles) for the reference population. White squares, electrode with the lowest intrinsic impedance (COVIDIEN-Kendall/31050522); black squares, electrode with the highest intrinsic impedance (Ambu/SU-00-C).

DISCUSSION

The use of bioimpedance methods for clinical research has advanced in a deliberate manner. Early applications focused on the estimation of body composition by using several prediction equations.[4] These approaches, however, have several limitations due to the technical and biological errors related to the assumptions of the constancy of the chemical composition of the fat-free body, as well as to the need to use appropriated cross-validated predictive equations developed in populations with similar biological and clinical characteristics to guarantee both the accuracy and the precision of the estimates when applying these equations in other populations (that is, their external validity).[1,40] Current approaches emphasize the use of raw whole-body bioimpedance measurements such as the BIVA method,[15] rather than derived variables to assess physiological, functional and nutritional status of individuals.[33,36,41] The main advantage of this method is the avoidance of any assumption about constant soft tissue hydration and its independence from reliance on body weight as a predictor in regression prediction equations. This approach only depends on the reproducibility and accuracy of bioimpedance measurements and intraindividual variability in body composition, as well as its simplicity and objectivity.[36]

Physical aspects for Ag/AgCl electrodes such as low intrinsic impedance, low electrode/skin contact impedance and the type of gel, among others, minimize the measurement errors.[8–10,12–14] Other considerations related to the electrode placement, such as careful placement and positioning of the electrodes, and avoidance of expired electrodes, also contribute to minimize measurement errors.[10,13,14] Ideally, every Ag/AgCl electrode should have the same intrinsic impedance;[11] nevertheless, as has been observed in this study (Table 1), substantial differences do exist between commercial electrodes (Table 2).

Theoretically, the ideal electrode should have negligible intrinsic impedance;[11] therefore, electrodes with the lowest intrinsic impedance are the most appropriate to perform bioimpedance measurements in humans.[11] According to Boone and Holder,[42] electrodes may be grouped according to the measured intrinsic impedance and relative to the impedance of unprepared skin, whose values at 50 kHz are between 100 and 200 Ω.

In this study, using 50 kHz, phase-sensitive device (BIA 101 Anniversary; AKERN-Srl) with a tetrapolar method and a sinusoidal AC of 240 μARMS, we measured the intrinsic value of *R* and Xc, of nine commercial Ag/AgCl electrodes selected (Table 1). As can be

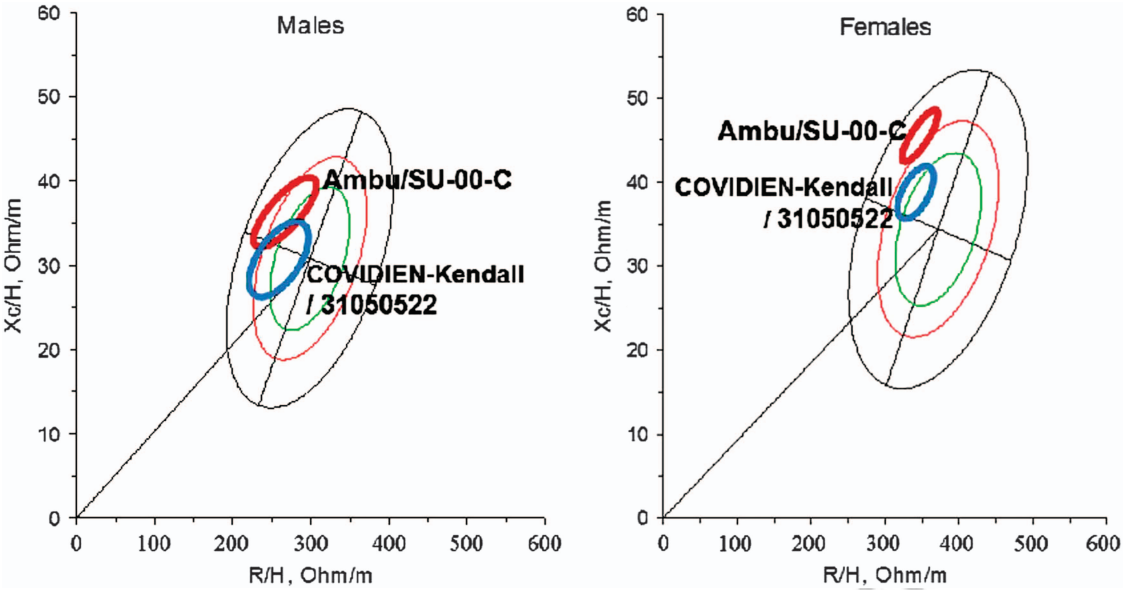

Figure 3. The 95% confidence ellipses for males and females plotted on the bivariate normal interval of reference population. COVIDIEN-Kendall/31050522 (blue line), electrodes with the lowest intrinsic impedance; Ambu/SU-00-C (red line), electrodes with the highest intrinsic impedance.

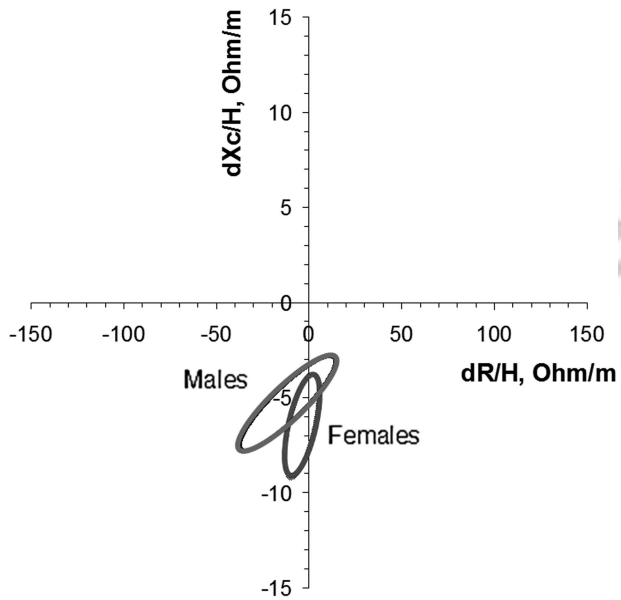

Figure 4. Paired graph for males and females. The paired graph shows the 95% confidence ellipse corresponding to the difference in the mean bioimpedance vector obtained with the electrodes COVIDIEN-Kendall/31050522 and Ambu/SU-00-C. Blue line, males; red line, females.

observed in Table 2, seven of the nine electrodes studied showed values $< 100\,\Omega$ ($11 \pm 30\,\Omega$), being all valid for noninvasive bioimpedance measurement at 50 kHz. Only two electrodes showed values $> 200\,\Omega$ ($347 \pm 665\,\Omega$).

The intrinsic impedance, measured with the tetrapolar method, is easy to measure by users (Figure 1). Four-electrode (tetrapolar) technique removes the contact impedance with respect to the two-electrode technique. In addition, it is less sensible to skin contact impedance mismatch (differences on the contact of the electrode's electrolyte with the skin), the status of the skin (abraded or not), time passed between the placement of the electrodes and the type of electrolyte used for the electrode. As skin contact impedance is unknown, when using the two-electrode technique produces great errors in the impedance measurement.[14] The effects of mismatch on contact impedance on the bioimpedance measurements with two commercial bioimpedance analyzer were tested in Bogónez-Franco *et al.*[14]

Given the large variability observed in intrinsic impedance (11–665 Ω), we used the lowest and the highest intrinsic impedance (that is, COVIDIEN-Kendall/31050522 and Ambu/SU-00-C, respectively) to analyze the effect of the intrinsic impedance of the electrodes on BIVA results in 35 healthy volunteers.

As can be seen in Figure 2, the individual vectors derived from bioimpedance measurements with the low intrinsic impedance electrode (COVIDIEN-Kendall/31050522) are within the 50% tolerance ellipse of the bivariate normal interval of reference population.[35] With increasing intrinsic impedance of electrodes (Ambu/SU-00-C), the vectors migrate ($P < 0.05$) into the upper left quadrant of the RXc graph and into the 75% tolerance ellipse. This displacement indicates a change in hydration classification from dehydration toward dehydration.[36] Figure 3 is consistent with Figure 2, given that the mean impedance vectors obtained with COVIDIEN-Kendall/31050522 for both males and females lie closest to the 50% tolerance ellipse of the reference population,[35] whereas the mean impedance vectors obtained with Ambu/SU-00-C lie between 75 and 95% percentiles. This finding of vector displacement in the same individuals, besides being statistically significant according to the paired one-sample Hotelling's T^2-test (Figure 4), can have adverse effects on clinical interpretation of bioimpedance measurements.

To our knowledge, this is the first study focused on analyzing the effects of the intrinsic impedance of commercial Ag/AgCl electrodes on displacement of impedance vectors using the BIVA method; hence, we cannot compare our results with other studies. Nevertheless, our findings indicate a need to clarify not only the measurement protocol and the characteristics of the impedance analyzer but also the characteristics of the electrodes used for bioimpedance measurements when analyzing body composition of hydration status. In this regard, it should be noted that currently most of the studies in the field of body composition analysis

focused on the BIVA method do not provide information about the characteristics of the electrodes. This is a major problem as it makes it difficult, or even impossible, to compare databases obtained from different reference populations if measurements are performed with electrodes with different intrinsic impedance values.

On the other hand, recent studies have evidenced that PhA is an independent prognostic marker in ill patients and is associated with mortality, nutritional and functional status, and with health-related quality of life.[43–45] PhA reference percentiles have been published as a simple and prognostically cutoff for detection of patients with cancer.[46] In this regard, we also found substantial differences in PhA values, ~1°, depending on the electrodes used. This reveals the need to provide the characteristics of the commercial electrodes (that is, intrinsic impedance, electrode/skin contact impedance, and so on) together with the BIAs and the measurement protocol when publishing reference data, as well as the need to use similar electrodes when using bioelectrical measurements in both clinical and epidemiological settings.

However, it should be noted that manufacturers of BIAs recommend specific electrodes and that researchers should ideally use the electrodes recommended by the manufacturers (example, BIATRODES for AKERN, IU0GELTD for ImpediMed, Bodystat electrode for BodyStat analyzers and so on) and consult the data sheets for the electrodes provided by the manufacturers. Nevertheless, actually most of the studies in the field of body composition analysis use electrodes that have not been designed specifically for bioimpedance measurements (example, electrodes for electrocardiogram) and these electrodes can be valid for bioimpedance measurements, provided that their intrinsic impedance is low. For these reasons, we consider that it is necessary that researchers who work in the field of body composition analysis with bioimpedance techniques incorporate the characteristics of the intrinsic impedance of the Ag/AgCl measured at the standard frequency for body composition analysis (that is, 50 kHz) and with a phase-sensitive BIA. Similarly, when comparing databases of body composition measurements obtained from different populations, it is necessary to guarantee that measurements are performed with the same protocol, and the same BIA and electrodes to reduce any potential sources of error.

Finally, it is also worth emphasizing that bioelectrical impedance analysis methods are accurate for body composition analysis both in clinical setting and in large epidemiological studies. Bioimpedance measurements are simple, repetitive, noninvasive and show a minimal intra- and interobserver variability.[47] In addition, the body composition analysis based on bioimpedance techniques requires inexpensive and portable equipment and thus is a good alternative to other methods such as dual X-ray absorptiometry or magnetic resonance imaging, which are more expensive and not feasible to conduct in the field studies. The results of this study indicate that the intrinsic impedance of the electrodes produces a displacement of impedance vector using the BIVA method; hence, this effect must be taken into consideration when performing bioimpedance measurements to minimize potential bias. However, this is not the reason for assuming that bioimpedance measurements are not accurate.

To summarize, a robust study of all physical characteristics of commercial Ag/AgCl electrodes commonly used in bioimpedance measures is necessary owing to the influence on interpretation on the BIVA method. The consensus in Ag/AgCl electrode use in bioimpedance measurement will allow researchers to compare and discuss more consistently the results.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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